KEYBOARD LAYOUT DESIGN OF DEVANAGRI TYPEWRITER

A Thesis Submitted
In Partial Fulfilment of the Requirements
for the Degree of
MASTER OF TECHNOLOGY

By

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to the
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CERTIFICATE

This is to certify that the present work on 'Keyboard Layout Design of Devanagri Typewriter ' by Lalit Gulati has been carried out under my supervision and has not been submitted elsewhere for the award of a degree.

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July, 1979.

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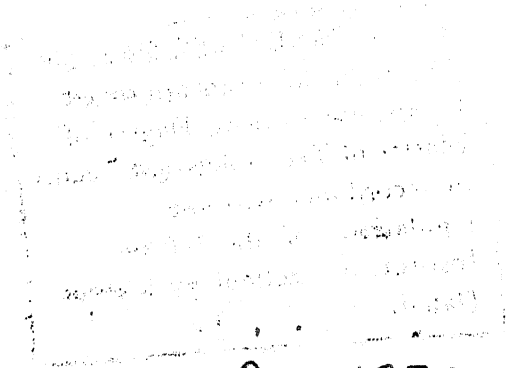
I also wish to express my thanks to Messrs. R.N. Biswas, Santokh Singh and O.P. Bajaj for the help and suggestions provided, during the course of this study.

I am also thankful to Mr. S.S. Pethkar for having typed the manuscript. Thanks are due to Shri Budhi Ram for having cyclostyled the thesis.

Lalit Gulati



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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Any man-machine system should be designed with both the technical and the human factors in view. In this thesis an attempt has been made to study the Devanagri typewriter from Ergonomic considerations.

Inspite of the gaining popularity of the Hindi language, the Devanagri typewriter does not have a 'standard' keyboard layout. This thesis exposes the deficiencies of some of the existing layouts, and subsequently a new layout has been proposed. The proposed layout has been designed keeping in view the frequency of alphabets, the load-bearing capacity of each finger, and the 'response time' associated with each key-position for a particular finger.

The frequency count of an alphabet, measured from various text-samples constitutes the load of that alphabet, while the load-bearing capacity of the finger is measured by its maximum tapping rate, over a fixed test interval. The desired load at each key-position is found using the 'response time' values for each key-position for a particular finger. The time values were obtained experimentally. The experimentation involved generation of electric signals through switches provided below the keys. These electric signals actuate the electronic digital clock (with a least count of 10 milliseconds), which measures the time interval between pressing of two keys.

Finally, the alphabets are allotted to the different key-positions depending on the load-giving us the proposed layout.

CHAPTER 1

INTRODUCTION

Technology is effective to the extent that men can operate and maintain the machines they design. Equipment design which consciously takes advantage of human capabilities and constrains itself within human limitations amplifies and increases system output. If it does not, system performance is reduced and the purpose for which the equipment was designed is endangered. This consideration is even more significant today than in the past, because the highly complex systems that we develop are pushing human functions more and more to their limits of efficient performance.

To ensure that machine operations are actually designed for human use, behavioral data, principles, and recommendations - in short, the Human Factors discipline - must be translated into meaningful design practices. Human factors engineering is the design of equipment, work environment, and work methods in accordance with human capabilities and limitations. It is that science which considers the human beings in the design of man made objects. The objectives of human consideration are to enhance the functional effectiveness of the designed system, and to maintain the health, safety, and satisfaction of the operator.

Human factors specialists are primarily concerned with.

1. Equipment Design characteristics,
2. Operating and Maintenance procedure, and
3. Characteristics of the working environment.

All these factors influence operator performance, considerably. There is a class of anthropometric design applications that involve only a small portion of the general space surrounding a person or that involve human mass properties or strength related to a piece or part of clothing or personal equipment that he normally wears. This class consists of applications involving characteristics of objects, devices, and machinery components that are handled by human beings or stepped on, sat in, carried, leaned against, or otherwise manipulated by humans. Here, in this thesis, we would be concentrating on one such application- the Devanagri typewriter.

With the extensive use of Hindi, nowadays, both in government and private circles, one would expect the Hindi Typewriter to have a standard layout. However, we have as many layouts as the number of companies manufacturing typewriters - though some layouts are only marginally different from others. Our attempt, here, would be to study the existing layouts, examine them from the human factors point of view, and subsequently to devise a layout which gives due importance to the ergonomic factors that are called into play.

Hopefully, the results of our analysis will serve as a basis for future design recommendations for keyboards, which may in turn ultimately be incorporated into design standards, and above all for the standardisation for the keyboard layout.

1.1 Organisation of the Thesis :

The following chapters deal with the literature review, the analysis of the existing Devanagri typewriter layouts, and the redesign of the layout. Chapter 2 deals with the work carried out

on the English typewriter, that is relevant to the study of the Devanagri typewriter. In Chapter 3, the data on frequency of Hindi alphabets, and the analysis of some of the existing layouts is presented. The methodology of devising a new layout, and the analysis of the redesigned layout, form the text of Chapter 4.

CHAPTER 2

LITERATURE SURVEY

To date, there is no published work on the design of the layout of the Devanagri typewriter, although extensive work has been carried out on the 'standard' English typewriter - both on its layout, and the associated operating postures. However, the study of Devanagri typewriter is vastly different - not only because of the large number of alphabets, prefixes and suffixes but also because of the structure of words commonly used in the Hindi language.

A brief survey of the work carried out on the English typewriter (that is relevant to the study of Hindi typewriter) was carried out.

In 1926, Klockenberg published a book, in German "Rationalisierung der Schreibmaschine und ihrer Bedienung" (7), dealing with the efficient design and operation of the English typewriter. He described how the keyboard layout was "uncomfortable and fatiguing." Based on detailed physiological considerations, and on experiments including time and motion studies, Klockenberg suggested a number of improvements, many of which are still valid. A.Dvorak (3), proposed a revised layout which was a considerable improvement on the 'standard' QWERTY layout, as most of the human factors were given their due importance. However the methodology he used is yet to be made public. Significant contributions were also made by Martin (9), and Remington and Rogers (11). Haaland, Wingert and Olson (5), analyzed the anatomical differences in the musculature of each finger, with a

view to find the capacities and fatigue resistance of different fingers. D. Ferguson, a physician, and Joan Duncan a physiotherapist, in their paper (4), 'Keyboard Design and Operating Posture,' deal with the drawbacks of the QWERTY layout, at some length. They also suggest some of the factors - from biomechanical considerations - that need to be taken into account while designing a new layout. Finally, Alden, Daniels, and Kanarick (1), review the major issues of keyboard design and operation.

These studies, however, "would be only of academic interest" to borrow words of Remington and Rogers, because of the costs and time which would be involved in retraining the millions of QWERTY operators. Not so, with the Devanagri typewriter, because of its 'non-standard' layout.

CHAPTER 3

STUDY OF THE EXISTING DEVANAGRI TYPEWRITERS

Before embarking on designing a new layout of the Devanagri typewriter, it is imperative that a study of the existing layouts, be made . This would not only expose the deficiencies, if any, of the existing layouts, but would also give an insight into the problems associated with redesigning the layout.

Any man-machine system, such as the Devanagri typewriter, should be studied both from the technical and the Ergonomics point of view. We would be analyzing the typewriter from the human factors point of view, as it is this aspect of the man-machine system, that has been neglected ever since. This aspect itself has many dimensions, and as such we would be restricting ourselves to just a part thereof. As far as the operating postures and the physiological factors, associated with the typewriter are concerned, we would leave them for the physicians and physiologists . Here, we would study the efficiency of the existing layouts keeping in view the human capabilities, or more specifically, the capacities of the different fingers.

It is common knowledge that the right hand can, generally speaking, bear more load than the left hand. Also, we know that the load-bearing capacity and resistance to fatigue decreases as we move from the index to the little finger . This fact is borne out clearly by the experiments of Haaland, Wingert, and Olson (5). Since the typist works essentially with his fingers, it is but natural, that

we study the layouts from this point of view. For such a study the load on each finger is required, and this can be measured best if we know the frequency of different alphabets.

3.1 Data on Frequency of Alphabets :

To find the frequency of a particular alphabet occurring in the Hindi texts, a reasonable sample size has to be taken. The size of the sample, and the accuracies associated with the frequencies is found using 'Work Sampling' techniques. The details are given below :

A 'Work Sampling' study consists of a large number of observations taken at random intervals (from random texts, in our case). In taking the observations the state or condition of the object of study is noted, and this state is classified into predefined categories, (different alphabets, in our case), of activity pertinent to the particular work situation. From the proportions of observations in each category, inferences are drawn concerning the total work activity (frequencies of alphabets, in our case) under study.

A list of alphabets is defined and prepared. Alphabets, with upper and lower case, as also those which should be necessarily together on one key, have been combined. The list appears on the left hand side of Table 3. Next step is to determine a suitable number of randomized observations. This was done by collecting small samples from different texts, notices, syllabi etc. This gives us the value of 'p' or percent of alphabets of one type contained in a total of N' alphabets, which is used for finding the actual number of alphabets or N, that are required for the study. The formula that follows state

the mathematical characteristics of the sample and is used to compute the sample sizes to any desired limits of accuracy or alternately for calculating the degree of accuracy.

$$SD_p = \sqrt{\frac{p(1-p)}{N}} \qquad (1)$$

where SD_p = standard deviation

p = percent of events of one type contained in Nobservations of the situation, expressed as a decimal.

N = total number of observations.

The formula given in (1) is the well-known formula for the standard deviation of a binomial distribution. SD_p is a measure of the variability of the value of p obtained from N observations. It possesses the following properties : 68 percent of sample of N size would give a value for p within $p \pm SD_p$; 95 percent of the samples of N size would give a value for p within $p \pm 2\ SD_p$.

Since we would be interested in one alphabet at a time (which would form one class, and all the other alphabets form the complementary class), the distribution would be binomial. For the sake of calculation of the size of samples the median value of p would be taken from the list of alphabets. This is done, because the formula holds good for high values of p ($p > .005$), and has to be changed for extremely low values of p.

If we wish to determine a value for p with our sampling error reduced to the point where we may say the chances are 95 out of 100

that p is correct to within $\pm$ s percent of p then

$$2\,SD_p = \frac{sp}{100} = 2\sqrt{\frac{p(1-p)}{N}} \qquad (2)$$

where s = accuracy.

If we wish to determine a value for p with our sampling error reduced to the point where we may say the chances are 95 out of 100 that p is correct to within $\pm$ 10 percent of p then

$$2\,SD_p = 0.1p = \sqrt{\frac{p(1-p)}{N}}$$

and

$$N = \frac{400}{p^2}\,p(1-p) \quad .$$

We would be considering the 95 % probability, with 10 % accuracy limits.

The initial value of p' found from N' observations is used for the calculation of N, and if this N is ~~less~~ more than N' the sample size taken is reasonable.

The value of p' (the median value of p' from the values of p' of all alphabets) was found to be 1.52. This gives N = 26,400. We took a sample size of 42,000 and measured the corresponding accuracies of the different alphabets. The value - frequency (p), and the accuracies for different alphabets is shown in Table 3.1.

The accuracy(s) is calculated from (2) :

$$s = \frac{2}{p}\sqrt{\frac{p(1-p)}{N}}$$

TABLE 3.1

FREQUENCY COUNT OF ALPHABETS APPEARING IN DIFFERENT TEXTS SAMPLES

Alphabets	ट ਟ	ज ज	च च	ग ग	छ	क क
Sample 1	115	65	73	54	43	182
Sample 2	95	64	61	56	48	193
Sample 3	130	61	44	49	47	188
Sample 4	122	73	65	63	55	210
Sample 5	125	45	48	72	58	215
Sample 6	108	58	65	76	44	195
Sample 7	115	57	43	47	62	197
Sample 8	114	50	42	43	65	210
Sample 9	91	41	54	41	63	193
Sample 10	123	42	52	54	48	173
Total	1138	556	547	555	533	1946
Percentage	2.710	1.310	1.303	1.322	1.268	4.620
Accuracy	5.9	8.52	8.54	8.48	8.66	4.54

Alphabets	ल ल	२ य	म म	ब ब	प प	न न
Sample 1	82	85	95	42	85	75
Sample 2	91	74	79	41	88	84
Sample 3	83	63	91	50	83	88
Sample 4	103	67	83	57	76	73
Sample 5	97	95	88	58	78	97
Sample 6	78	92	77	45	79	115
Sample 7	70	75	68	61	82	131
Sample 8	95	79	102	64	91	119
Sample 9	89	74	85	65	83	98
Sample 10	108	87	100	69	104	100
Total	896	791	868	552	849	980
Percentage	2.086	1.884	2.066	1.315	2.022	2.334
Accuracy	6.75	7.1	6.78	8.51	6.86	6.38

Alphabets	७ २	ि ी	स स	ड ठ	^ २	ब ब
Sample 1	55	284	123	46	33	70
Sample 2	59	263	111	51	41	68
Sample 3	43	260	114	52	37	93
Sample 4	48	215	135	47	38	91
Sample 5	58	210	156	48	45	78
Sample 6	47	283	93	43	48	85
Sample 7	58	295	143	59	52	84
Sample 8	66	257	186	58	31	80
Sample 9	62	292	90	58	36	87
Sample 10	62	258	143	55	62	104
Total	558	2617	1294	517	423	840
Percentage	1.318	6.230	3.082	1.231	1.008	2.000
Accuracy	8.5	3.9	5.55	8.79	9.72	6.9

Alphabets	ट	ठ	ड	ढ	त	थ
Sample 1	62	38	60	62	124	258
Sample 2	58	38	41	46	72	360
Sample 3	43	40	41	41	62	323
Sample 4	31	40	63	62	104	338
Sample 5	37	41	50	58	80	317
Sample 6	45	60	47	48	90	319
Sample 7	48	53	43	45	76	310
Sample 8	50	40	45	37	74	306
Sample 9	41	42	38	43	82	305
Sample 10	62	60	31	31	66	356
Total	487	462	469	485	840	3192
Percentage	1.159	1.076	1.118	1.150	2.000	7.600
Accuracy	9.06	9.4	9.22	9.1	6.9	3.53

Alphabets	द	ध	न	प	फ	ब
Sample 1	68	57	48	40	53	60
Sample 2	75	54	39	42	55	47
Sample 3	49	62	37	33	49	50
Sample 4	54	51	53	38	47	46
Sample 5	59	51	47	50	45	42
Sample 6	63	57	47	39	51	38
Sample 7	62	39	44	36	58	38
Sample 8	71	39	52	45	55	34
Sample 9	48	43	40	48	54	41
Sample 10	49	76	51	47	57	60
Total	598	529	458	418	524	466
Percentage	1.425	1.260	1.078	.976	1.247	1.110
Accuracy	8.17	8.69	9.39	9.87	8.73	9.26

Alphabets	ਓ	ਹ	ਲ	ਰ	ਸ	ਦ
Sample 1	39	153	49	151	55	53
Sample 2	38	112	41	140	58	47
Sample 3	41	106	39	152	53	39
Sample 4	39	102	38	144	62	47
Sample 5	49	108	33	147	61	39
Sample 6	33	107	39	140	65	48
Sample 7	43	122	42	153	43	53
Sample 8	51	99	43	144	51	44
Sample 9	57	97	48	139	53	44
Sample 10	61	163	54	144	41	53
Total	453	1169	426	1454	542	465
Percentage	1.078	2.766	1.014	3.462	1.291	1.108
Accuracy	9.39	5.86	9.69	5.24	8.58	9.37

Alphabets	ਤਾ	ਯ	ਤੈਂ	ਮੱ	ਜੀ	ਤੇ
Sample 1	73	0	28	49	31	39
Sample 2	65	0	33	54	30	43
Sample 3	72	0	27	49	30	51
Sample 4	85	0	29	33	10	51
Sample 5	53	0	22	42	39	51
Sample 6	57	0	18	38	37	57
Sample 7	48	0	19	39	38	60
Sample 8	62	0	17	43	38	39
Sample 9	61	0	25	49	36	43
Sample 10	45	0	28	31	25	25
Total	621	0	246	427	314	459
Percentage	1.480	0	0.572	1.018	0.748	1.093
Accuracy	8.02	-	12.9	9.67	11.28	9.33

Alphabets	उ	•	ह्न	.	ए	:
Sample 1	51	120	45	0	35	0
Sample 2	52	125	48	0	51	0
Sample 3	38	97	43	0	52	0
Sample 4	35	115	62	0	38	0
Sample 5	47	110	49	0	47	0
Sample 6	62	107	65	0	43	0
Sample 7	43	120	58	0	75	0
Sample 8	55	111	56	0	62	0
Sample 9	68	123	52	0	55	0
Sample 10	75	112	35	0	63	0
Total	526	1140	513	0	521	0
Percentage	1.252	2.716	1.222	0	1.240	0
Accuracy	8.72	5.92	8.82	-	8.76	-

Alphabets	/	ͼ	\	ɔ	‿	ा
Sample 1	54	73	53	58	47	93
Sample 2	42	68	46	45	48	98
Sample 3	39	55	38	47	47	100
Sample 4	48	42	35	46	53	120
Sample 5	47	63	54	51	51	106
Sample 6	54	45	47	53	43	117
Sample 7	50	37	48	43	47	115
Sample 8	38	58	49	46	45	108
Sample 9	38	32	52	38	46	110
Sample 10	46	51	32	33	58	109
Total	456	524	454	460	485	1076
Percentage	1.085	1.249	1.081	1.095	1.036	2.562
Accuracy	9.36	8.73	9.38	9.32	9.58	6.09

Alphabets	T	
Sample 1	375	38
Sample 2	360	52
Sample 3	362	58
Sample 4	380	65
Sample 5	345	66
Sample 6	321	49
Sample 7	360	43
Sample 8	300	48
Sample 9	298	60
Sample 10	292	34
Total	3393	493
Percentage	8.078	1.055
Accuracy	3.43	9.50

It should be noted that the total sample of N = 42,000 was obtained from further subsamples of about 4,200 each. These subsamples were taken from a wide range from novels, textbooks, notices, circulars, syllabi etc. so as to give us an unbiased frequency distribution.

3.2 Analysis of Existing Layouts :

Having obtained the frequency table (Table 3.1) three of the existing layouts were analyzed. We will call these Layout 1, Layout 2, and Layout 3. Using Table 3.1, the load on fingers, hands, and rows is evaluated. This is shown in Table 3.2a, 3.2b, and 3.2c.

From these one can clearly see the following deficiencies:

Layout 1 :

1. Of the total load, only 85.3 % is concentrated on the three rows that are normally used (as explained in Chapter 4) while the remaining has been either neglected or kept with numerals.
2. The left hand bears 48.129 out of 85.3 i.e. 56.4 % of load, while the right bears the remaining 43.6 %.
3. The Index finger of right hand has almost 25 % of total load. Next is little finger of left hand with 20 % of total load, whereas it should have the minimum (approximately 9.7 %).
   The load bearing heirarchy is Right Index Finger - RIF, Left Little Finger- LLF, Left Index Finger-LIF, Left Middle Finger-LMF, Left Ring Finger-LRF, Right Middle Finger-RMF, Right Ring Finger -RRF, and Right Little Finger-RLF -whereas the heirarchy should be (as we will see in Chapter IV).
   RIF , RMF , LIF, LMF, RRF, LRF , RLF , LLF .

TABLE 3.2a

LAYOUT 1

	LEFT HAND						RIGHT HAND						
	LITTLE		RING	MIDDLE	INDEX		INDEX		MIDDLE	RING	LITTLE		TOTAL
TOP ROW	ऽ	∪	म	त	ज	ल	ब	ट	ठ	ढ	ध	×	
	७	९	म	त	ज	ल	ब	प	व	च	ख	=	
	1.795	1.654	2.066	2.71	1.31	2.086	2.334	2.022	2.00	1.346	1.346	-	20.626
MIDDLE ROW	'	२	क	ट	ळ	भ	श्र	श	स	ट	ड	.	
	.	२	क	ि	ह	ी	र	ा	स	य	श	%	
	3.801	7.6	4.62	4.49	2.766	4.291	4.480	9.826	3.082	1.884	1.231	-	47.071
BOTTOM ROW	८	ञ	ळ	ट	ठ	-	ह्व	ऊ	ढ	झ	ध	-	
	/	ग	ब	अ	इ	-	ट	उ	ए	ए	ए	-	
	2.334	1.322	1.315	1.639	2.33	-	2.543	1.492	1.216	2.154	1.258	-	17.603
TOTAL	18.506		8.001	8.839	12.783		21.697		6.298	5.341	3.835		85.300
	48.129						37.171						85.300

TABLE 3.2b

LAYOUT 2

	LEFT HAND						RIGHT HAND						
	LITTLE		RING	MIDDLE	INDEX		INDEX		MIDDLE	RING	LITTLE		TOTAL
TOP ROW	[illegible] [illegible]	[illegible] [illegible]	[illegible] म	[illegible] त	[illegible] ज	[illegible] [illegible]	[illegible] न	ट प	[illegible] व	[illegible] घ	[illegible] [illegible]	. ,	
	1.795	1.654	2.066	2.71	1.31	2.086	2.334	2.022	2.00	1.303	1.346	-	20.62[illegible]
MIDDLE ROW	- -	T .	[illegible] [illegible]	[illegible] क	[illegible] [illegible]	[illegible] [illegible]	[illegible] [illegible]	श्र र	[illegible] T	[illegible] स	[illegible] य	[illegible] [illegible]	
	-	5.278	7.6	4.62	4.49	2.766	4.291	4.48	8.826	3.082	2.814	1.231	49.47[illegible]
BOTTOM ROW	- -	[illegible] /	[illegible] ग	[illegible] ब	[illegible] अ	[illegible] [illegible]	[illegible] द	[illegible] उ	[illegible] [illegible]	[illegible] [illegible]	[illegible] [illegible]	- -	
	-	2.334	1.322	1.315	1.639	2.33	2.543	1.492	1.216	2.154	1.258	-	17.60
TOTAL	11.061		10.988	8.645	14.621		17.162		12.042	6.539	6.649		87.7[illegible]
			45.315						42.392				87.7[illegible]

TABLE 3.2 c

LAYOUT 3

	LEFT HAND						RIGHT HAND						
	LITTLE		RING	MIDDLE	INDEX		INDEX		MIDDLE	RING	LITTLE		TOTAL
TOP	त्	ध्	म्	द्	ट	-	ज्	ड़्	ई	ए	रू	ऋ	
ROW	त्र	ध	म	दा	त	थ	ग	ष	य	उ	र	ॠ	
	1.093	1.108	1.291	1.303	2.71	1.26	1.322	1.348	3.106	1.492	4.476	7.6	28.109
MIDDLE	द्व	क्	फ्	ट्	न्	ड	ठ	ट	ऱ	स्	९	/	
ROW	ब	क	म	ा	ना	ज	व	प	फ	स	७	\	
	1.33	4.62	2.066	8.11	2.334	1.31	2.0	2.022	5.2	3.082	1.318	2.166	35.558
BOTTOM	श्	ह्य	त्र	ह	द्य	ल्	:	?	श्र	)	(		
ROW	शा	ह	अ	ख	द	ल	?	,	|	(-	़	-	
	.7	2.766	2.052	1.268	1.50	2.086	1.095	-	3.58	-	1.75	-	16.797
TOTAL	11.617		5.409	10.681	11.200		7.787		11.886	4.574	17.310		80.464
			38.907						41.557				80.464

Layout 2 :

1. Of the total load, only 87.707 % is concentrated on the three rows that are normally used, while the remaining has been either neglected or kept with numerals.
2. The left hand bears 45.315 out of 87.707 i.e. 52 % of the total load while the remaining i.e. 48 % is borne by the right hand.
3. The Index finger of right hand bears maximum load, but far too excess of its capacity. Again, the little finger of left hand that should bear the least load bears 12.5 % of load.
   The heirarchy is
   RIF, LIF, RMF, LLF, LRF, LMF, RLF, and RRF.

Layout 3 :

1. Of the total load only 80 % is concentrated on the three rows normally used, while the remaining has been either neglected, or kept with numerals.
2. The little finger of right hand bears the maximum load i.e. 23% of the total, next is right index. The little finger of left hand is third with 14 % of the load.
   The heirarchy is
   RLF, RMF, LLF, LIF, LRF, RIF, LRF and RRF.
3. The load is concentrated mainly on the top two rows, whereas Ergonomically it should have 53 % on middle row, and the rest almost equally distributed between the top and bottom row (as explained in Chapter 4).

Considering the above deficiencies, it is imperative that a new layout be designed, which minimizes, if not removes, these deficiencies, and above all creates a basis for standardisation of the layout.

CHAPTER 4

METHODOLOGY OF REDESIGNING THE LAYOUT

Any layout, old or new, should meet the following conditions.

1. The layout should have all the alphabets that are generally used in the Hindi text.
2. Load on the left hand should be less than or atmost equal to that on the right hand.
3. The distribution of load on each finger, should be according to the capacity of that finger.
4. The inter-row movement (i.e. hopping in between the rows) should be kept minimum - that is the distribution of load on different rows should be judicious.

The first condition gives us the number of keys required on each row. This is obtained from the following considerations :

The total number of alphabets are :

Alphabets with upper and lower case	:	13
Others	:	48

Hence, the minimum number of keys required = $13 + \frac{48}{2}$ =37 keys.

A typewriter has four rows in all. The numerals which form an essential part of the keyboard layout are generally placed on the top-most row. The alphabets are, if possible, distributed among the remaining three rows. These are the three rows that are normally

used. However, due to human limitations, 37 keys cannot be assigned to these three rows. Hence, a few alphabets, 4 in number, with the lowest frequency counts, are placed on the top-most row with the numerals - giving us the breakup of Table 4.1 for the three rows under study :

TABLE 4.1

Number of keys in Each Row

Row	Number of Keys
Top Row	12
Middle Row	12
Bottom Row	11

The assignment of keys to the different fingers is shown in Figure 4.1.

The second and the third conditions can be incorporated in one, if we have the load capacities of each finger of both the hands.

The musculature of the hand places limitations on the ability of the fingers to respond in a keyboard task. Haaland, Wingert, and Olson (5), have measured the maximum pushing force for each finger of the adult male hand. Their results are given in Table 4.2.

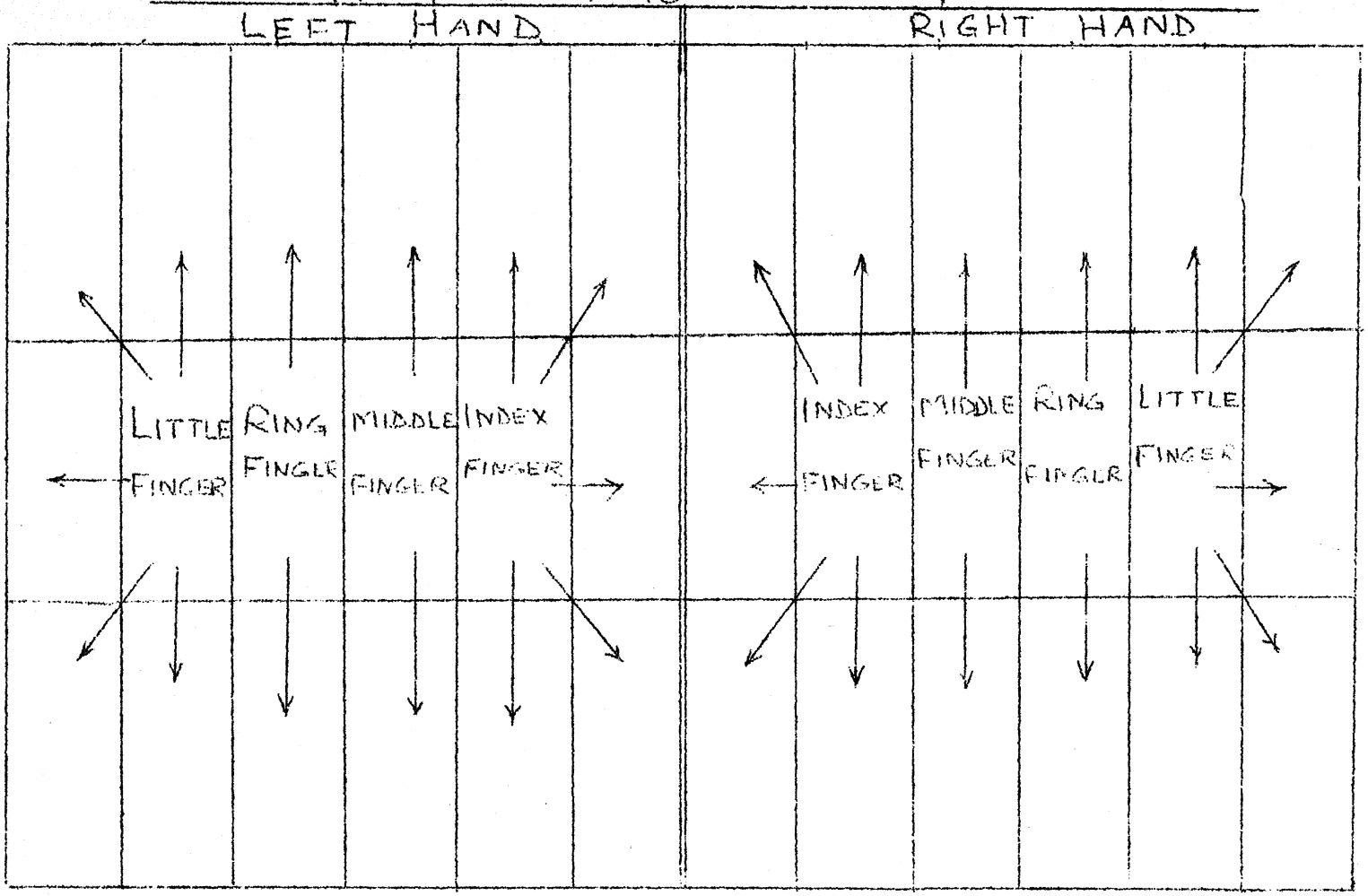
ASSIGNMENT OF KEYS TO DIFFERENT FINGERS
LEFT HAND
RIGHT HAND
LITTLE FINGER
RING FINGLE
MIDDLE FINGER
INDEX FINGER
INDEX FINGER
MIDDLE FINGER
RING FINGLR
LITTLE FINGER

FIGURE 4.1

TABLE 4.2

Maximum Pushing Force for Each Finger(lbs)

	Index	Middle	Ring	Little
Average	24	22	18	12
Range	17-31	17-26	12-22	6-19

Haaland, et al, have attributed the differences in applicable force as reflecting the anatomical differences in the musculature of each finger.

They found that the data on maximum finger tapping rate, correlates with that of Table 4.2 on maximum pushing force, and used that as a measure of the capacities of different fingers. In the light of the data on finger strength, one would expect that fatigue would vary as a function of the finger being used. Haaland verified that susceptability to fatigue increases as one moves progressively from the index finger to the little finger. In our case, the maximum tapping rate (which is used, as a measure of the capacities) for different fingers, taken over 15 seconds test intervals, is given in Table 4.3a and Table 4.3b.

Table 4.3a

Maximum Tapping Rate of Fingers of Left Hand

	Little	Ring	Middle	Index
Tapping	48	57	63	66
Rate	49	57	62	66
	49	57	64	65
	47	57	63	67
	47	57	63	66
Average	48	57	63	66

Table 4.3b

Maximum Tapping Rate of Fingers of Right Hand

	Index	Middle	Ring	Little
Tapping	71	69	62	56
Rate	70	68	62	57
	70	68	62	57
	69	70	62	55
	70	70	62	55
Average	70	69	62	56

The maximum tapping rate, expressed as a percentage, gives the T_p-values as shown in Table 4.4a and 4.4b.

Table 4.4 a

Capacities of fingers of Left Hand or T_p - values.

	Little	Ring	Middle	Index	Total
Capacity	9.776	11.609	12.831	13.442	47.658

Table 4.4b

Capacities of fingers of Right Hand or T_p - values

	Index	Middle	Ring	Little	Total
Capacity	14.257	14.053	12.627	11.405	52.342

Tables 4.4a and 4.4b show that the right hand should bear 52.342 % of the load, while the remaining i.e. 47.658 % be borne by the left hand.

To satisfy the last condition, and also to get the loads at each key position the following methodology was adopted. The typist places his fingers in the normal position on the keyboard, and then types the particular words which have been chosen such that the

time interval between the pressing of a base key say, right hand index finger, middle row, and another key of the left hand say, little finger top row extreme, can be measured. This is done for all keys assigned to the left hand with one particular basekey on the right hand. The process is repeated with different base keys, The whole experimentation is done for each hand- giving 'response times' or t_i-values which are recorded. In our experimentation, three t_i - values were recorded, for one basekey, and the average value used. There were four different base key positions - the index, middle, ring and the little finger at their normal positions on the middle row, forming the base key positions. All this was done for both the hands, and, finally, the whole process was carried out with three typists to get unbiased results. It is assumed that if the typists have different speeds, then the time interval between pressing of two keys would correspondingly be different.

The time values (t_i-values) are as shown in Table 4.5.

4.1 Experimental Details :

The equipments used were :

1. Devanagri typewriter with the requisite number of keys on each row.
2. An electronic digital clock with an accuracy to measure to the nearest hundredth of a second.
3. Switches for the generation of electrical signals.

Table 4.5

ti-values to the nearest hundredth of a second.

Right Hand

Typist 1

Base Left Hand Index Finger

	Index		Middle	Ring	Little Finger	
Top-Row	30	32	31	44	42	59
	31	31	32	47	45	58
	32	31	33	46	47	58
Average	31	31.33	32	45.67	44.67	58.33
Middle-Row	13	10	14	19	22	30
	12	10.5	15	19	22	30.5
	13	11	14.5	18	22	31
Average	12.67	10.5	14.5	18.67	22	30.5
Bottom-Row	31	21	38	52	44	-
	31	20	37.5	50	43	-
	31	21	37.5	49	43	-
Average	31	20.67	37.67	50.33	43.33	-

Base Left Hand Middle Finger

	Index		Middle	Ring	Little	
Top Row	33	33	33	52	47	60
	32	32	32	51	46	60.5
	32	33	32	50	47	60
Average	32.33	32.67	32.33	51	46.67	60.17
Middle Row	14	11	14	19	24	32
	14	11	15	19	23	31.5
	15	12	16	19	23	31
Average	14.33	11.33	15	19	23.33	31.5
Bottom Row	33	22	41	53	47	-
	32	22	41	55	47	-
	33	21	41	53.5	46.	-
Average	32.67	21.67	41	53.83	46.67	-

Base Left Hand Ring finger

	Index		Middle	Ring	Little	
Top Row	37	37	39	62	50	67
	37	37	39	63	52	67
	37	38	39	62	52	67
Average	37	37.33	39	62.33	51.33	67
Middle Row	16	12	18	22	26	37
	16.5	12.5	19	23	26	37.5
	15	13	18.5	25	27	37.5
Average	15.83	12.5	18.5	23.33	26.33	37.33
Bottom Row	38	25	49	64	50	-
	37	25	49.5	66	51	-
	36	26	49	63	50.5	-
Average	37	25.33	49.17	64.33	50.5	-

Base Left Hand Little finger :

	Index		Middle	Ring	Little	
Top Row	40	41	40	70	52	68
	42	42	39	72	53	68.5
	41	43	41	70	53.5	69
Average	41	42	40	70.67	52.83	68.5
Middle Row	17	16	19	23	27.5	37
	16	14	18	24	27	37.5
	18	15	20	25	27	37.5
Average	17	15	19	24	27.17	37.33
Bottom Row	42	28	49	69	55	-
	42	28	49	70	53	-
	42	28	49	71	53	-
Average	42	28	49	70	53.67	-

Typist 2

Base Left Hand Index Finger

	Index		Middle	Ring	Little	
Top Row	32.5	32	32	46	43.5	60
	33.5	34	32.5	47	45	61
	33.5	34	33.5	47	48.5	61.5
Average	33.17	33.33	33	46.67	45.67	60.83
Middle Row	14.5	13	16	21	24	30
	15	12.5	16.5	22	23.5	32
	15.5	13	16	22	24.5	31.5
Average	15	12.83	16.17	21.67	24	31.17
Bottom Row	33	32	31.5	47	44	-
	33	34	33	47	46	-
	32.5	32	35	47	45	-
Average	32.83	32.67	33.17	47	45	-

Base Left Hand Middle Finger

	Index		Middle	Ring	Little	
Top Row	35	34	34	52	48	63
	34	34	35	55	49	62
	34	34	35	54	50	62.5
Average	34.33	34	34.67	53.67	49	62.5
Middle Row	16	13	15.5	21	25	35
	16	13.5	16	20	26	33
	16.5	12.5	16.5	21	26	34
Average	16.17	13	16	20.67	25.67	34
Bottom Row	35	35	36	54	49	-
	36	34	37	56	51	-
	36	35	38	56	51	-
Average	35.67	34.67	37	55.67	50.33	-

Base Left Hand Ring Finger

	Index		Middle	Ring	Little	
Top Row	40	41	39	65	53	69
	41	40.5	40	63	55	70
	40.5	39	40	63	55	70
Average	40.5	40.17	39.67	63.67	54.33	69.67
Middle Row	18	15	19	25	28	39
	19	15	20	25	29	38
	20	15	22	26	30	37
Average	19	15	20.67	25.33	29	38
Bottom Row	40	41	39	66	55	-
	42	41	39	63	55	-
	40	41	42	62	55	-
Average	40.67	41	40	63.67	55	-

Base Left Hand Little Finger

	Index		Middle	Ring	Little	
Top Row	37	37	39	62	51	69
	36	38	38	62.5	53	68
	36	38	38	64	55	67
Average	36.33	37.67	38.33	62.83	53	68
Middle Row	16	15.5	19	25	26	37
	16.5	15	21	27	26	39
	16.5	15	21	27	27	39
Average	16.33	15.17	20.33	26.33	26.33	38.33
Bottom Row	37	38	39	63	55	-
	37	38.5	40	63	55	-
	37	38.5	40	63	52	-
Average	37	38.33	39.67	63	54	-

Typist 3

Base Left Hand Index Finger

	Index		Middle	Ring	Little	
Top Row	31	32	31	43	42	59
	33	32	31	46	44.5	57.5
	32	31.5	33	46	44.5	58
Average	32	31.83	31.67	45	43.67	58.17
Middle Row	14	12.5	15	20	22	30
	13	11.5	15.5	19	22	30
	13.5	13	15	20	21.5	30
Average	13.5	12.33	15.17	19.67	21.83	30
Bottom Row	32	33	31	45	44	-
	32	31	33	47	45	-
	32	30	33	47	45	-
Average	32	31.33	32.13	46.13	44.67	-

Base Left Hand Middle Finger

	Index		Middle	Ring	Little	
Top Row	32	31	33	52	48	61
	32	32.15	33	50	48	62
	32	32	33	49	48	62
Average	32	31.83	33	50.33	48	61.67
Middle Row	15	12	15	20	24	35
	15	12.5	16	21	26	33
	15	12.5	17	20.5	27	32
Average	15	12.33	16	20.5	25.67	33.33
Bottom Row	33	32	34	51	48	-
	33	32	34	48	48	-
	32	32	33	48	51	-
Average	32.67	32	33.67	49	49	-

Base Left Hand Ring Finger

	Index		Middle	Ring	Little	
Top Row	38	38	42	63	52	68
	39	38	40	65	55	68
	40	38	40	63	54	69
Average	39	38	40.67	63.67	53.67	68.33
Middle Row	17	13	18	23	27	38
	17.5	13	20	25	27	41
	17.5	14	21	25	29	42
Average	17.33	13.33	19.67	24.33	27.67	40.33
Bottom Row	38	37	43	65	55	-
	39	42	40	67	53	-
	39	41	42	68	53	-
Average	38.67	40	41.67	66.67	53.67	-

Base Left Hand Little Finger

	Index		Middle	Ring	Little	
Top Row	41	41	42	68	58	68
	42	41	42	73	59	72
	43	41	43.5	73	60	70
Average	42	41	42.5	71.33	59	70
Middle Row	18	15	20	24	28	39
	16	16	22	25	28	40
	17	16	22	25	28.5	41
Average	17	15.67	21.33	24.67	28.17	40
Bottom Row	43	43	41	69	59	-
	43	43	44	73	59	-
	43	45	44	72	59	-
Average	43	43.67	43	71.33	59	-

LEFT HAND

Typist 1

Base Right Hand Index Finger

	Little		Ring	Middle	Index	
Top Row	69	38	48	37	36	36
	68	39	47	36.5	36	36
	68.5	39	49	37	36.5	36
Average	68.5	38.67	48	36.83	36.17	36
Middle Row	31	23	20	16	12	15.5
	31	24	21	15.5	11.5	16
	31	24.5	20	16.5	12.5	16
Average	31	23.83	20.33	16	12	15.83
Bottom Row	86	58	58	32	24	36
	85	57	59	32	24.5	36
	82	57.5	58	32	24.5	35
Average	84.33	57.5	58.33	32	34.33	35.67

Base Right Hand Middle Finger

	Little		Ring	Middle	Index	
Top Row	72	40	55	32	30	38
	72	41	55.5	32	31	37
	71	40	54	32	30.5	38
Average	71.67	40.33	54.83	32	30.5	37.67
Middle Row	33	25	21	16	12	16
	34	24	21	16.5	12	17
	34	24	20	16	12.5	16
Average	33.67	24.33	20.67	16.17	12.17	16.33
Bottom Row	89	60	61	33	26	38
	86	62	60	31	25.5	38
	85	61	60.5	32	25.5	38
Average	86.67	61	60.5	32	25.67	38

Base Right Hand Ring Finger

	Little		Ring	Middle	Index	
Top Row	81	46	61	39	41	42
	80.5	46	62	39.5	42	42
	80	44	60	40	42	42
Average	80.5	45.33	61	39.5	41.67	42
Middle Row	37	28	23	18	14.5	17
	36	27	24	17.5	15.5	16.5
	37.5	27	24	19	15	18
Average	36.83	27.67	23.67	18.17	15	17.83
Bottom Row	100	68	65	46	28	41
	98	67.5	67	43	28.5	43
	96	68	66	46	28.5	42
Average	98	67.87	66	45	28.33	42

Base Right Hand Little Finger

	Little		Ring	Middle	Index	
Top Row	84	46	65	48	46	46
	84	46	65.5	49	46	47
	84	48	64.5	48.5	46	46
Average	84	46.67	65	48,5	46	46.33
Middle Row	38	28.5	25	19	16	19.5
	39	28.5	24	19	15.5	20
	39	29	24	18.5	15	20
Average	38.67	28.67	24.33	18.83	15.5	19.83
Bottom Row	103	75	72	47	30.5	47
	103	73	71	46	30.5	46
	106	73	71	48	32	46
Average	104	73.67	71.33	47	31	46.33

Typist 2

Base Right Hand Index Finger

	Little		Ring	Middle	Index	
Top Row	69	39	49	37	35	36
	70	39	48	37	37	36.5
	71	39	48	36.5	37	36.5
Average	70	39	48.33	36.83	36.33	36.33
Middle Row	32	24	21	17	13	16
	31	23	21	16.5	12	15
	31	23.5	21	16	12.5	14
Average	31.33	23.5	21	16.5	12.5	15
Bottom Row	87	59	59	33	25	38
	85	60	61	32	26	37
	86	61	58	33	26	37
Average	86	60	59.33	32.67	25.67	37.33

Base Right Hand Middle Finger

	Little		Ring	Middle	Index	
Top Row	73	42	55	31	31	36
	73	41	52	33	34	37
	73	40	52	34	30	39
Average	73	41	53	32.67	31.67	37.33
Middle Row	34	26	22	17	12	15.5
	35	25	22	17.5	12.5	16
	34	26	22	17.5	12.5	17
Average	34.33	25.67	22	17.33	12.33	16
Bottom Row	90	60	60	32	28	38
	91	62	60.5	32	27	37.5
	91	62	60.5	33	27	37.5
Average	90.67	61.33	60.33	32.33	27.33	37.67

Base Right Hand Ring Finger

	Little		Ring	Middle	Index	
Top Row	82	49	65	40	38	42
	82	52	65	41	40	43
	82.5	52	65	41	41	44
Average	82.17	51	65	40.67	39.67	43
Middle Row	38	29	24	19	15	18
	38	30	23	20	17	19
	38	31	24.5	20.5	17.5	18.5
Average	38	30	23.83	19.83	16.5	18.5
Bottom Row	99	67	66	48	30.5	43
	98	69	66.5	49	30.5	43
	98	69	66	49.5	30	43
Average	98.33	68.33	66.17	48.83	30.33	43

Base Right Hand Little Finger

	Little		Ring	Middle	Index	
Top Row	86	47	66	49	48	47
	86.5	47	67	52	48	49
	86	48	68	51	48	49.5
Average	86.17	47.33	67	50.67	48	48.5
Middle Row	41	31	26	22	18	19
	41	30.5	27	22	17.5	20
	40.5	31	28	22	18.5	20.5
Average	40.83	30.83	27	22	18	19.83
Bottom Row	99	78	75	48	31	48
	103	79	75	47.5	30	46
	101	79	74.5	46	30	48
Average	101	78.67	74.83	47.17	30.33	47.33

Typist 3

Base Right Hand Index Finger

	Little		Ring	Middle	Index	
Top Row	73	42	52	39	38	37.5
	73	42.5	51	40	38	39.5
	73	44	50.5	38	38	39
Average	73	43.17	51.17	39	38	38.67
Middle Row	33	26	22	18	15	16
	35	28	23	19	15.5	16
	35	27.5	24	18.5	14	15.5
Average	34.33	27.83	23	18.5	14.83	15.83
Bottom Row	88	58	57	35	27	37
	87	62	57	35	27.5	36
	87	62	57	36	26.5	36.5
Average	87.33	60.67	57	35.33	27	36.5

Base Right Hand Middle Finger

	Little		Ring	Middle	Index	
Top Row	75	43	56	35	33	40
	74	42.5	57	38	33	40
	73	41.5	57	37.5	32.5	40.5
Average	74	42.33	56.67	36.83	32.83	40.17
Middle Row	37	28	23	18	14	18
	36	25.5	25	17	14.5	17
	36.5	26.5	26	17.5	14.5	16
Average	36.5	26.67	24.67	17.5	14.33	17
Bottom Row	92	63	62.5	35	27	32
	91	61	63	37.5	29	33
	90.5	62.5	63	36.5	30	35
Average	91.17	62.17	62.83	36.33	28.67	33.33

Base Right Hand Ring Finger

	Little		Ring	Middle	Index	
Top Row	83	52	64	47	40	44
	85	51	64	45	42	44
	84.5	50.5	64.5	44	42	44.5
Average	84.17	51.17	64.17	45.33	41.33	44.17
Middle Row	39	33	27	22	16	17
	41	33.5	26	22.5	18	19.5
	40.5	32	27.5	21.5	17.5	20
Average	40.17	32.83	26.83	22	17.87	18.83
Bottom Row	100	69	68	49	33	40
	97	70.5	68	51	33	38
	97	71	67.5	50.5	33	38.5
Average	98	70.17	67.83	50.17	33	38.83

Base Right Hand Little Finger

	Little		Ring	Middle	Index	
Top Row	87	47	68	49	49	47
	86	47.5	68	51	52	49
	86	48.5	67	51	51	50
Average	86.33	47.67	67.67	50.33	50.67	48.67
Middle Row	42	33	27	23	18	20
	43	31	28	22.5	19	20
	42	31	28.5	23	20	21
Average	42.33	31.67	27.83	22.83	19	20.33
Bottom Row	102	79	77	50	33	49
	104	82	77	50.5	35	50
	105	82	76.5	51	35	47
Average	103.67	81	76.83	50.5	34.33	48.67

4. Adjustable base for the switches to measure time for keys on different rows.

The switches are adjusted on the base, such that on pressing the particular keys, electric signals are generated. These electrical signals are fed to the electronic digital clock. On receiving an electric signal the clock starts, and stops on the receipt of the next signal. Thus, by having the switches at the required positions the 'response time' or t_i-values can be measured.

The photograph of the setup is shown in Fig. 4.2.

4.2 Procedure for redesigning layout :

For a particular finger, with a particular base key, one would expect that the minimum value will occur at the position where the finger is normally placed - this has been found to be true from the ti-values. Let this minimum value of time, for a given finger, be t_k . Next, the ratio t_k / t_i is found for all keys assigned to that finger with one particular base key. The results shown in Table 4.6. Having done this for all the four base key positions, the average of these ratios is calculated - called A-values as shown in Table 4.6. This is done to eliminate the effect of perception load time. Finally, an overall average for each key position assigned to a particular finger, is obtained by taking an average of the A-values for the three typists. This final, overall average, value is called R_i where i denotes the i^{th} key position of a particular finger. The R_i-values are shown in Table 4.7a and 4.7b. All these calculations are done for all the fingers of both the hands.

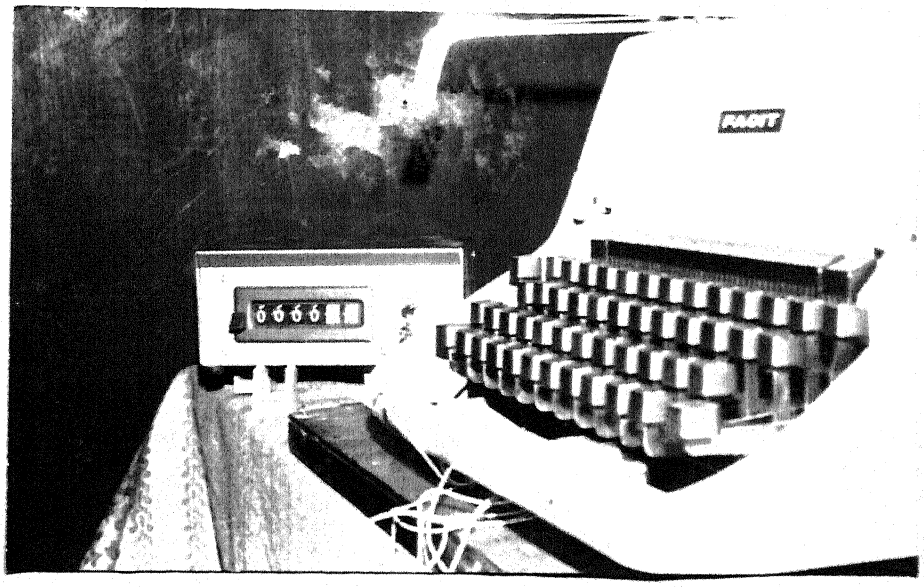

FIGURE 4.2

TABLE 4.6

t_k/t_i - values

RIGHT HAND

(Base left hand Index finger- I.F., Middle finger - M.F., Ring finger - R.F., and Little finger L.F.).

Typist 1

TOP ROW

Base	Index		Middle	Ring	Little	
I.F.	.339	.335	.453	.407	.493	.377
M.F.	.351	.347	.465	.372	.500	.387
R.F.	.338	.335	.475	.375	.514	.394
L.F.	.366	.357	.475	.339	.514	.397
Average (A-values)	.3485	.3435	.467	.3733	.5053	.3888

MIDDLE ROW

Base	Index		Middle	Ring	Little	
I.F.	.829	1.000	1.000	1.000	1.000	.721
M.F.	.791	1.000	1.000	1.000	1.000	.739
R.F.	.789	1.000	1.000	1.000	1.000	.705
L.F.	.883	1.000	1.000	1.000	1.000	.728
Average (A-values)	.823	1.000	1.000	1.000	1.000	.7233

BOTTOM ROW

Base	Index		Middle	Ring	Little	
I.F.	.339	.508	.385	.370	.507	-
M.F.	.347	.523	.366	.354	.500	-
R.F.	.338	.494	.376	.362	.522	-
L.F.	.357	.536	.388	.342	.505	-
Average (A-values)	.3453	.5153	.3788	.3570	.5085	-

Typist 2

TOP ROW

Base	Index		Middle	Ring	Little	
I.F.	.387	.385	.489	.465	.525	.394
M.F.	.379	.382	.462	.385	.523	.411
R.F.	.370	.373	.519	.399	.534	.416
L.F.	.418	.404	.529	.418	.496	.387
Average (A-values)	.3885	.3858	.4998	.4168	.5195	.4020

MIDDLE ROW

Base	Index		Middle	Ring	Little	
I.F.	.855	1.000	1.000	1.000	1.000	.770
M.F.	.804	1.000	1.000	1.000	1.000	.754
R.F.	.789	1.000	1.000	1.000	1.000	.764
L.F.	.929	1.000	1.000	1.000	1.000	.688
Average (A-values)	.8443	1.000	1.000	1.000	1.000	.744

BOTTOM ROW

Base	Index		Middle	Ring	Little	
I.F.	.391	.393	.487	.461	.532	-
M.F.	.364	.375	.432	.372	.509	-
R.F.	.369	.366	.515	.399	.528	-
L.F.	.410	.396	.512	.418	.488	-
Average (A-values)	.3835	.3825	.4865	.4125	.5143	-

Typist 3

TOP ROW

Base	Index		Middle	Ring	Little	
I.F.	.385	.387	.478	.437	.500	.376
M.F.	.385	.387	.486	.408	.523	.415
R.F.	.342	.351	.484	.381	.515	.405
L.F.	.373	.382	.502	.345	.478	.403
Average (A-values)	.3713	.3768	.4875	.3928	.504	.3998

MIDDLE ROW

Base	Index		Middle	Ring	Little	
I.F.	.913	1.000	1.000	1.000	1.000	.729
M.F.	.822	1.000	1.000	1.000	1.000	.768
R.F.	.769	1.000	1.000	1.000	1.000	.688
L.F.	.922	1.000	1.000	1.000	1.000	.705
Average (A-values)	.8565	1.000	1.000	1.000	1.000	.7225

BOTTOM ROW

Base	Index		Middle	Ring	Little	
I.F.	.385	.394	.471	.426	.489	-
M.F.	.378	.385	.475	.419	.525	-
R.F.	.345	.333	.471	.363	.515	-
L.F.	.364	.359	.495	.345	.478	-
Average (A-values)	.3680	.3678	.4780	.3883	.5018	-

LEFT HAND
(Base Right Hand Index Finger -I.F., Middle Finger- M.F., Ring Finger-R.F., Little Finger-L.F.)

Typist I

TOP ROW

Base	Little		Ring	Middle	Index	
I.F.	.347	.615	.424	.435	.332	.333
M.F.	.338	.604	.377	.505	.399	.323
R.F.	.343	.611	.388	.459	.359	.357
L.F.	.342	.614	.374	.388	.337	.335
Average (A-values)	.3425	.6110	.3908	.4468	.3568	.3370

MIDDLE ROW

Base	Little		Ring	Middle	Index	
I.F.	.768	1.000	1.000	1.000	1.000	.758
M.F.	.722	1.000	1.000	1.000	1.000	.745
R.F.	.751	1.000	1.000	1.000	1.000	.842
L.F.	.741	1.000	1.000	1.000	1.000	.782
Average (A-values)	.7455	1.000	1.000	1.000	1.000	.7818

BOTTOM ROW

Base	Little		Ring	Middle	Index	
I.F.	.278	.415	.349	.500	.493	.336
M.F.	.280	.398	.341	.505	.474	.320
R.F.	.282	.408	.358	.402	.529	.357
L.F.	.275	.388	.341	.401	.500	.335
Average (A-values)	.2788	.4023	.3473	.4520	.4990	.3370

Typist 2

TOP ROW

Base	Little		Ring	Middle	Index	
I.F.	.336	.603	.435	.448	.344	.344
M.F.	.352	.625	.416	.530	.389	.330
R.F.	.365	.589	.367	.488	.416	.384
L.F.	.358	.651	.403	.434	.375	.371
Average (A-values)	.3528	.6170	.4053	.4750	.3810	.3573

MIDDLE ROW

Base	Little		Ring	Middle	Index	
I.F.	.750	1.000	1.000	1.000	1.000	.833
M.F.	.748	1.000	1.000	1.000	1.000	.771
R.F.	.789	1.000	1.000	1.000	1.000	.892
L.F.	.755	1.000	1.000	1.000	1.000	.908
Average (A-values)	.7605	1.000	1.000	1.000	1.000	.8510

BOTTOM ROW

Base	Little		Ring	Middle	Index	
I.F.	.273	.391	.355	.506	.487	.335
M.F.	.283	.419	.364	.536	.451	.327
R.F.	.303	.438	.359	.406	.544	.384
L.F.	.305	.392	.361	.467	.593	.380
Average (A-values)	.2910	.4100	.3598	.4788	.5188	.3565

Typist 3

TOP ROW

Base	Little		Ring	Middle	Index	
I.F.	.381	.644	.448	.474	.390	.383
M.F.	.361	.631	.435	.475	.436	.357
R.F.	.389	.642	.417	.485	.432	.405
L.F.	.367	.667	.411	.454	.375	.390
Average (A-values)	.3745	.6460	.4278	.4720	.4083	.3838

MIDDLE ROW

Base	Little		Ring	Middle	Index	
I.F.	.811	1.000	1.000	1.000	1.000	.937
M.F.	.729	1.000	1.000	1.000	1.000	.843
R.F.	.818	1.000	1.000	1.000	1.000	.949
L.F.	.749	1.000	1.000	1.000	1.000	.935
Average (A-values)	.7768	1.000	1.000	1.000	1.000	.916

BOTTOM ROW

Base	Little		Ring	Middle	Index	
I.F.	.317	.458	.403	.523	.549	.406
M.F.	.292	.428	.392	.481	.499	.445
R.F.	.335	.469	.395	.438	.542	.460
L.F.	.306	.392	.361	.452	.553	.390
Average (A-values)	.3125	.4368	.3878	.4735	.5358	.4253

TABLE 4.7a

OVERALL AVERAGE $t_k/t_{i's}$ or R_i-values For Right Hand

RIGHT HAND

	Index		Middle	Ring	Little	
Top Row	.3694	.3687	.4848	.3943	.5096	.3968
Middle Row	.8413	1.000	1.000	1.000	1.000	.7299
Bottom Row	.3656	.4219	.4478	.3859	.5082	-

TABLE 4.7b

OVERALL AVERAGE t_k/t_{is} or R_i- values for Left Hand

LEFT HAND

	Little		Ring	Middle	Index	
Top Row	.3566	.6247	.4079	.4646	.3820	.3594
Middle Row	.7609	1.000	1.000	1.000	1.000	.8496
Bottom Row	.2941	.4164	.3649	.4681	.5179	.3729

To get the frequency loads, at the different key positions, the objective taken, is to have the same weighted time for each key position. That is, the frequency loads at the different key positions should be inversely proportional to their t_i-values. For example; let the response time for the little finger of left hand at the top row extreme position be t_1, and for any other key position assigned to the same finger be t_2, then, if the frequency loads at these two positions are x_1 and x_2, respectively, they will bear the following relationship

$$x_1 t_1 = x_2 t_2$$

Similar analysis is done for all keys assigned to a particular finger.

Inherent, in this method is the satisfaction of the fourth condition, mentioned in the beginning of this chapter. The load on any row is inversely proportional to the time taken for the finger to press a key on that row, starting from its normal positions.

Now, knowing the capacity of each finger, we have the total load on a particular finger, called T_p (from Table 4.4a and 4.4b), equal to the sum total of all the frequency loads at the different key positions of a particular finger. Thus, knowing T_p, and t_i, t_k values, the x_i- values or the frequency load at different key positions is calculated.

Mathematically,

1. $$\sum_{i=1}^{n} x_i = T_p$$

where

x_i = frequency load at i^{th} key position of a particular finger.

n = total number of keys assigned to that particular finger.

T_p = capacity of the finger, i.e. the maximum tapping rate of that particular finger.

2. $x_1 t_1 = x_2 t_2 \ldots\ldots = x_k t_k = \ldots\ldots x_n t_n$.

where t_i's are the 'response times' as explained in the text, t_k is the minimum of all t_i's for a particular finger.

Since $$x_1 = \frac{x_k t_k}{t_1}$$

$$x_2 = \frac{x_k t_k}{t_2} \qquad \text{etc.}$$

to satisfy (1) we have

$$\frac{x_k t_k}{t_1} + \frac{x_k t_k}{t_2} + \ldots\ldots\ldots + \frac{x_k t_k}{t_n} = T_p$$

or

$$x_k = \frac{T_p}{\frac{t_k}{t_1} + \frac{t_k}{t_2} + \ldots\ldots \frac{t_k}{t_n}}$$

The average values of t_k/t_i are obtained as explained in the text and are called R_i's .

Knowing T_p (Table 4.4a and 4.4b) and R_i's (Table 4.7a and 4.7b) x_k can be calculated. Finally the frequency loads at different key positions of a particular finger, i.e. x_i-values can be calculated from 2. Doing this analysis for each finger, will give us the frequency load at each key position of the typewriter.

The x_i-values are shown in Table 4.8.

Finally, from the values of frequency of various alphabets (Table 3.1) the alphabets are allotted to the different key positions. The strategy used is to combine the alphabet of highest frequency with that of lowest, if both are separate. This is done, so that the alphabets with low accuracy (s) and the ones with high accuracy are combined to get a uniform overall accuracy. In case of conflict, the alphabets bearing a close relationship are placed next to each other. This gives us a revised layout as shown in Table 5.

4.3. Analysis of the Re-designed Layout .

The revised layout is seen to have 54 % of load on right hand, and 44 % on left.

The load on different fingers is according to their capacities except for the right hand little finger bearing more load than left hand ring finger.

The distribution of load on the different rows is quite close to the optimum found in Table 4.8.

Finally, the three rows normally used account for 98.6 % of the total load.

TABLE 4.8

Frequeney Load at Each Key Position

x_i- values

	LEFT HAND						RIGHT HAND						Total
	LITTLE		RING	MIDDLE	INDEX		INDEX		MIDDLE	RING	LITTLE		
Top Row	1.0097	1.7688	2.671	3.0844	1.4745	1.3873	1.5642	1.5613	3.5253	2.7968	1.8664	1.4533	24.1630
Middle Row	2.154	2.8314	6.5484	6.6389	3.86	3.2795	3.5625	4.2345	7.2716	7.093	3.6269	2.6734	53.7741
Bottom Row	.8327	1.1789	2.3895	3.1077	1.9991	1.4394	1.5481	1.7865	3.2562	2.7372	1.8614	-	23.1367
TOTAL	10.7755		11.6089	12.8310	13.4398		14.2171		14.0531	12.4270	11.4814		
	48.6552						52.1786						

TABLE 5

REVISED LAYOUT

	LEFT HAND						RIGHT HAND						
	LITTLE		RING	MIDDLE	INDEX		INDEX		MIDDLE	RING	LITTLE		TOTAL
TOP ROW	ढ ड़ 1.231	[illegible] म 2.066	[illegible] उ 2.355	श्र • 3.734	[illegible] ग 1.322	[illegible] ज 1.31	ट प 2.022	[illegible] व 2.0	[illegible] स 3.082	/ [illegible] 2.345	[illegible] न 2.334	? (2.344	26.145
MIDDLE ROW	[illegible] [illegible] 1.318	[illegible] [illegible] 2.369	क् क 4.62	प् प 6.23	ठ ह 3.742	• [illegible] 3.055	[illegible] ा 3.598	रु र 4.476	[illegible] ा 8.826	[illegible] [illegible] 7.6	[illegible] [illegible] 2.503	[illegible] [illegible] 2.349	50.686
BOTTOM ROW	^ [illegible] 1.008	च् च 1.303	ठ ए 2.35	[illegible] अ 2.556	[illegible] ड 2.34	[illegible] ब 1.315	[illegible] थ 1.884	[illegible] ल 2.086	[illegible] त 2.334	त्र उ 2.345	[illegible] ट 2.309	- -	21.830
TOTAL	9.295		9.325	12.520	13.084		16.066		14.242	12.29	11.839		
	44.224						54.437						
	98.661												

Scope for Further Work :

The emphasis in our revised layout, lay on the capacities of the different fingers. Further work is possible by taking into consideration, the relationship that the alphabets bear to one another. The new layout could then be designed as facility location problem, using the time matrix and the relationship matrix. Nevertheless, the conditions mentioned in the beginning of Chapter 4, have to be incorporated. A similar sort of study needs to be done for the linotypewriters.

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